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ANNUAL TECHNICAL REPORT

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Submitted by

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The following material constitutes our annual report regarding ONR Grant No. N00014-91-J-4017. The primary objectives of the research are to numerically simulate stratus, stratocumulus, and cumulus clouds in the marine boundary layer. This will include the formation, evolution, and dissolution of the clouds and the area covered by the cloud fields. If a large enough domain can be covered, then the change from one type of cloud to another would be investigated. Also the change from open cell to closed cell type convection and the formation of cloud streets could be investigated.

Another objective is to increase our understanding of conditions in the marine boundary layer. What determines the vertical profiles of humidity, temperature, and cloud characteristics in space and time? What causes the changing depth of the boundary layer? What are its interaction with the clouds in and out of the boundary layer?

A third objective is to compare various numerical models among themselves and with observations. Such comparisons should indicate ways to improve the model and whether practical predictive cloud models for the marine boundary layer can be constructed.

Our primary emphasis during the first year of the grant was to make preparations for the Third International Cloud Modeling Workshop and to run our cloud model on the Marine Boundary Layer (MBL) case which was provided as one of the test cases.

The IAS two-dimensional, time-dependent cloud model was run with all four atmospheric soundings produced by Betts and Boers for the 7 July 1987 FIRE case. The model was run with 25 m grid intervals in the vertical and horizontal directions. Initial conditions were taken from the atmospheric

soundings. The u-component wind speed varied from +2 m s^{-1} to -2 m s^{-1} in the vertical. No rain was simulated -- coalescence (autoconversion) of cloud droplets to rain was disabled in the code. The first two figures (Figs. 1 and 2) indicate model characteristics.

Cloud development in the four cases was quite different. Figures 3 and 4 show the evolution of the cloud top heights and the linear cloud fraction (squaring these values would give an approximation to the area coverage). The results compare quite well with the observations presented in the Betts and Boers paper. The cloud tops are limited by the strong inversions in the atmospheric soundings. The fraction of cloud is probably a result of the relative humidity in the soundings. The results compared with the observations indicate that a considerable amount of information is contained in the initial soundings. Figure 5 shows the two-dimensional depiction of the clouds after 150 min of real time simulation. There is a marked difference in the cloud field from the "clear" condition (at top) to the overcast condition (at the bottom of the figure).

A graduate student has been assigned to the project and is helping in the analysis of data. In addition he has run a cloud condensation nuclei model, using the cloud conditions simulated in the 2D model, and has compared the number of cloud droplets produced and the mean size of the droplets with observational data provided to us by University of Washington researchers. The parcel model (provided by David Johnson) produced 64 droplets cm^{-3} while the observations show an average of 48 droplets cm^{-3}. The mean size of the parcel model droplets increase with height while the observations show a steady average size. The most obvious explanation for the differences is the lack of any mixing in the parcel model, but further analysis is needed.

Other Activities

Approximately 50 scientists attended the Third International Cloud Modeling Workshop. Twenty-three modelers requested the MBL case; seven reported on their results at the Workshop. Discussions concerning the results ran over three days. A summary of the results is being prepared for a WMO report on the workshop. Preliminary results indicated that initial conditions were very important for the model results. Also, the methods of treating turbulent mixing were different among the models and affected results. Atmospheric radiation was treated by most but not all of the modelers. Both bulk water and detailed microphysics were used in the models. More data were called for. Contact has been made with other modelers indicating that a modeling workshop concerning the ASTEX data set might be productive.

Next Year's Activities

We plan to finish the analysis of the 2D model results and move on to large eddy simulation in three dimensions using the model of Chin-Ho Moeng and the 3D cloud model of Clark and associates.

MODEL

2 DIMENSIONAL SLAB SYMMETRIC TIME DEPENDENT
FINITE DIFFERENCE GRID

DOMAIN

5.0 KM HORIZONTAL - 200 DIVISIONS
2.5 KM VERTICAL - 100 DIVISIONS

MICROPHYSICS - BULK PARAMETERIZATIONS

CLOUD WATER
ALSO RAIN, GRAUPEL AND SNOW -(TURNED OFF)

BOUNDARIES

TOP - SOLID - NO FLOW THROUGH
SIDES - FLOW THROUGH PERMITTED
SURFACE - SOLID - TEMPERATURE MAY VARY
ABOUT A PRESCRIBED LEVEL

Figure 1.

CASES

TWO CASES HAVE BEEN RUN

MODEL IS INITIALIZED WITH THE SOUNDINGS IN BETTS AND BOERS (1990)

THE SEA SURFACE TEMPERATURES WERE EXTRAPOLATED ADIABATICALLY FROM ABOVE

SINUSOIDAL 0.3 C VARIATION IN TEMPERATURE AT SURFACE INITIALLY - WAVE LENGTH 2 KM

WIND IS THE SAME FOR ALL RUNS AND VARIES AS

ALT (KM)	VELOCITY (M S^{-1})
0.	1.
1.	-2.
3.	2.

CASE 1

SURFACE TEMPERATURE VARIES ABOUT +0.5 C WARMER THAN INITIAL SOUNDING

CASE 2

SURFACE TEMPERATURE VARIES ABOUT INITIAL VALUE IN SOUNDING

CUMULUS SOUNDING SURFACE TEMPERATURE IS EXTRAPOLATED FROM 997 MB LEVEL

Figure 2.

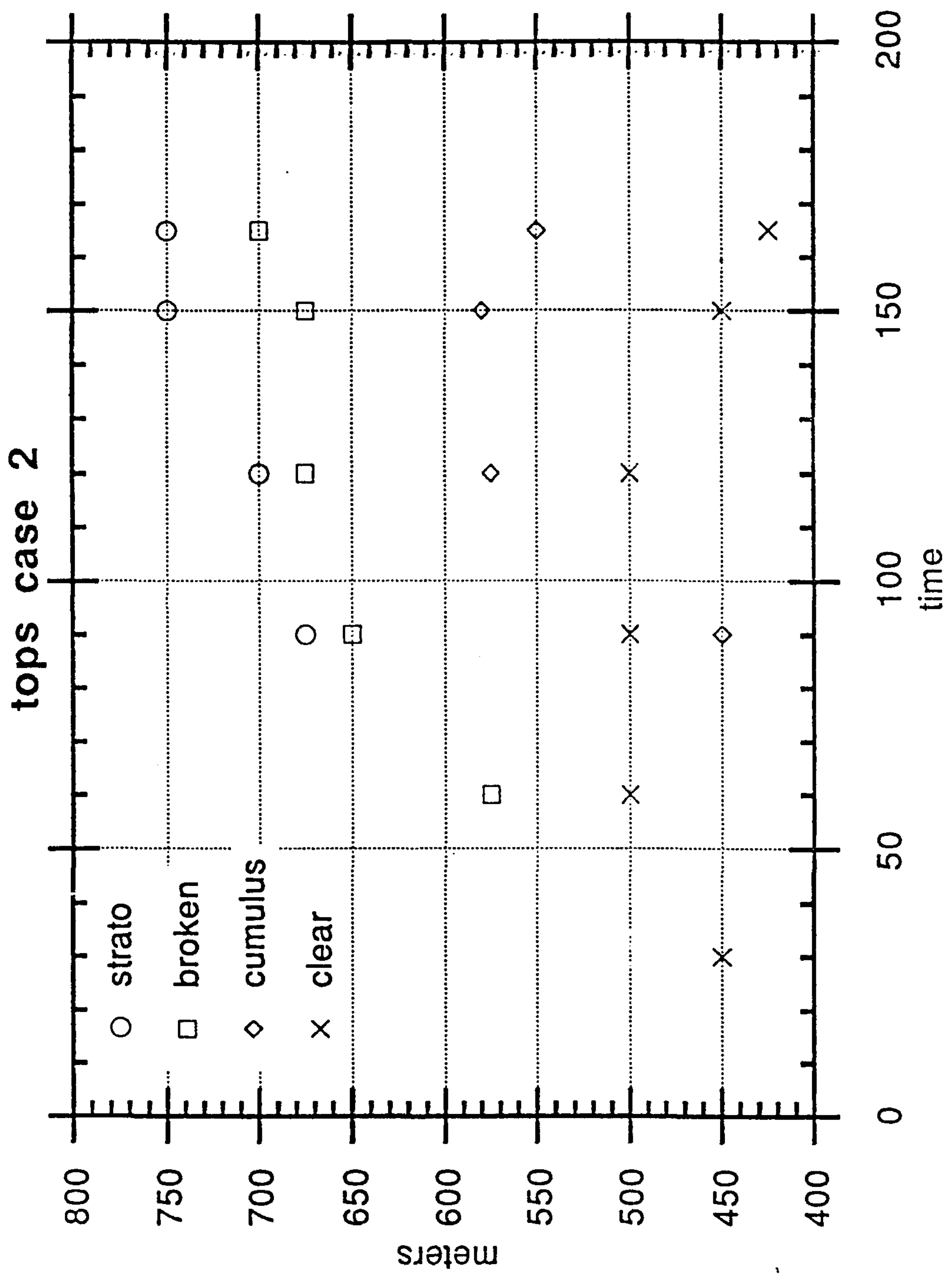
tops case 2
strato
broken
cumulus
clear
meters
800
750
700
650
600
550
500
450
400
time
0
50
100
150
200

Figure 3.

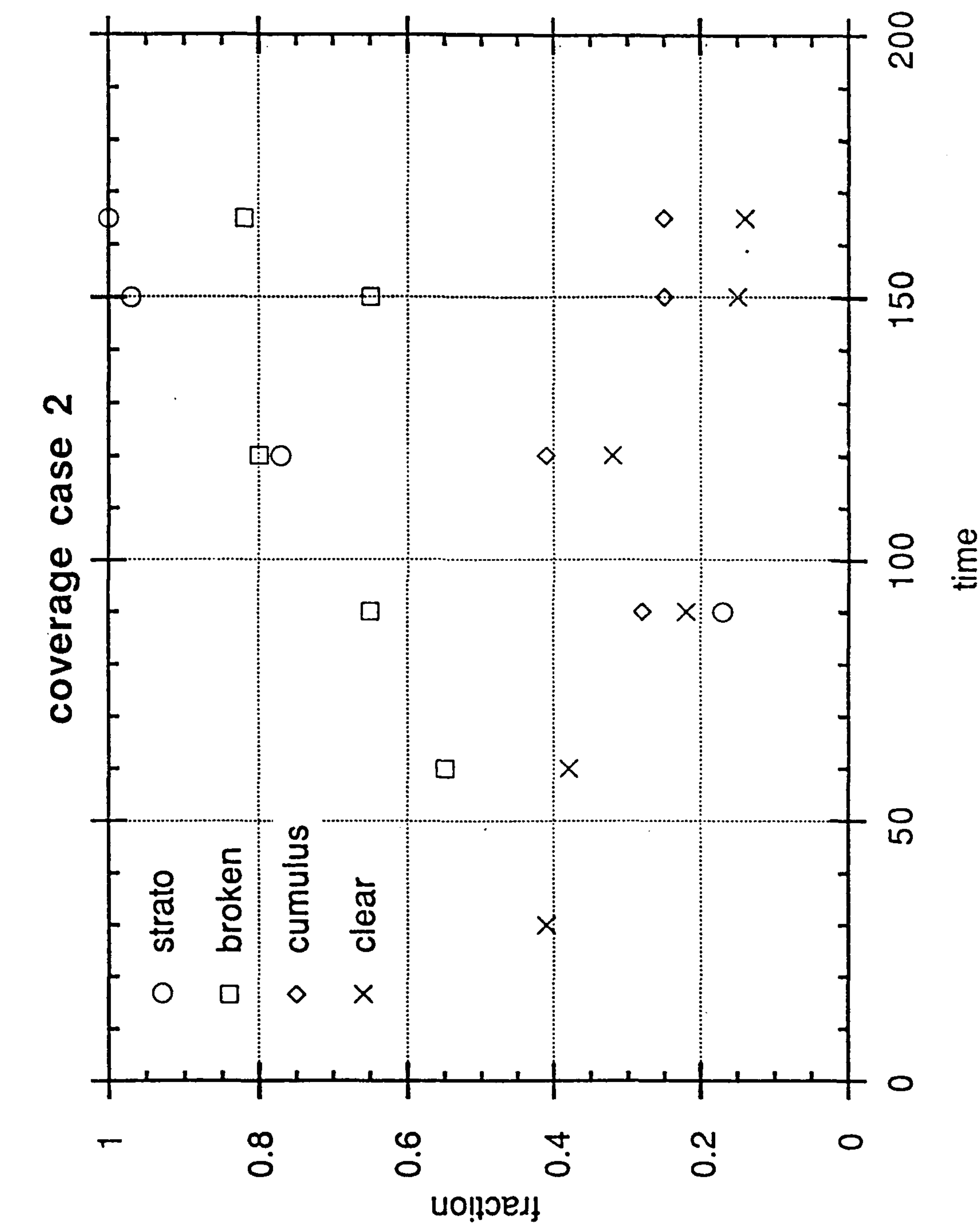
coverage case 2
strato
broken
cumulus
clear
fraction
1
0.8
0.6
0.4
0.2
0
time
0
50
100
150
200

Figure 4.

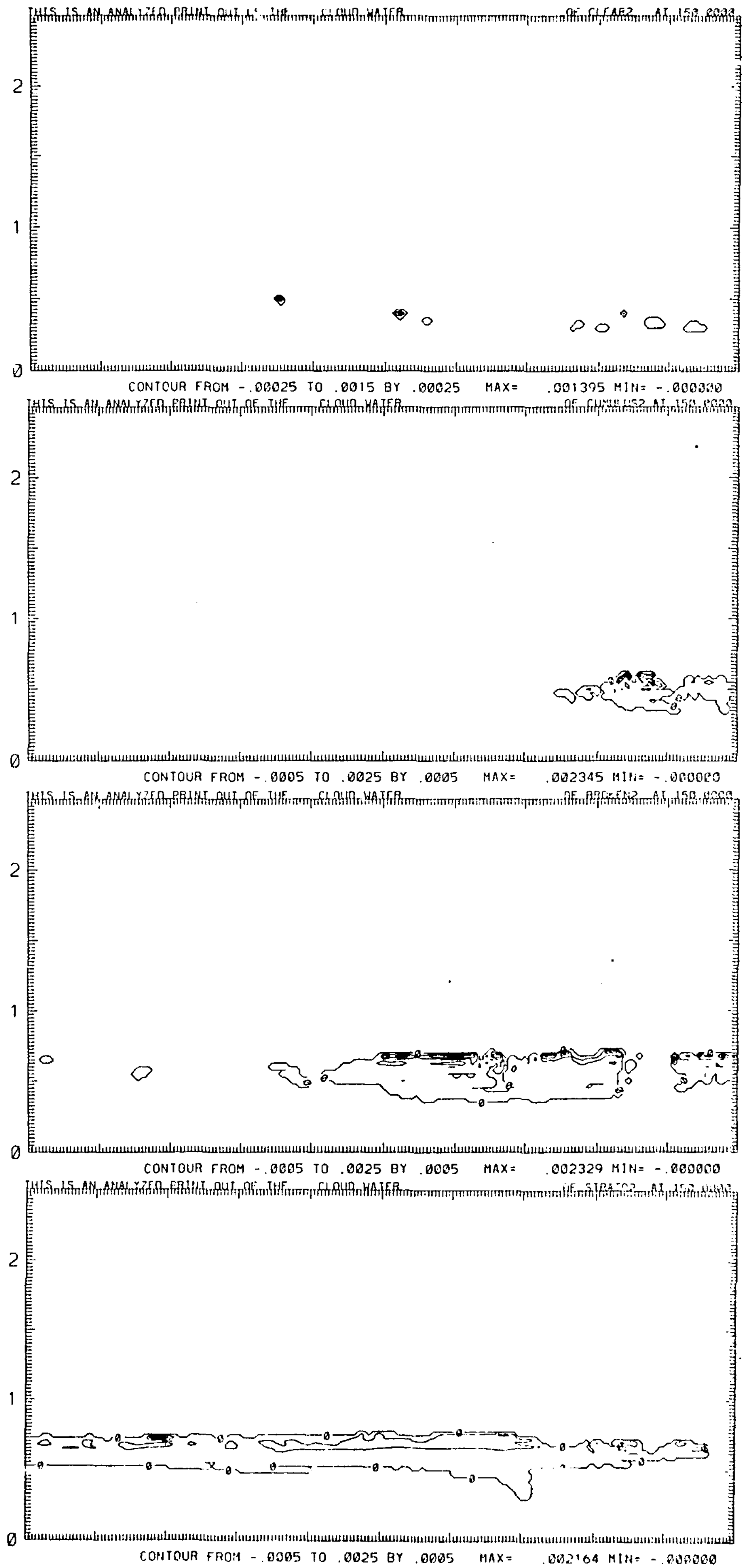
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Figure 5.